USAARL Report No. 2000-14

The UH-60 Cockpit Airbag System: A Preliminary Anthropometric Analysis

by
Frederick T. Brozoski, John S. Crowley, B. Joseph McEntire, Philip A. Johnson, Victor J. Cruz, and Clifton L. Dalgard

Aircrew Protection Division

May 2000

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Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release, distribution unlimited
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) USAARL Report No. 2000-14	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION U.S. Army Aeromedical Research Laboratory 6b. OFFICE SYMBOL *(If applicable)* MCMR-UAD	7a. NAME OF MONITORING ORGANIZATION U.S. Army Medical Research and Materiel Command
6c. ADDRESS *(City, State, and ZIP Code)* P.O. Box 620577 Fort Rucker, AL 36362-0577	7b. ADDRESS *(City, State, and ZIP Code)* 504 Scott Street Fort Detrick MD 21702-5012
8a. NAME OF FUNDING / SPONSORING ORGANIZATION 8b. OFFICE SYMBOL *(If applicable)*	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS *(City, State, and ZIP Code)*	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
62787A	30162787A878	EA	DA302870

11. TITLE *(Include Security Classification)*
The UH-60 Cockpit Airbag System: A Preliminary Anthropometric Analysis (U)

12. PERSONAL AUTHOR(S)
Fred Brozoski, John Crowley, Joseph McEntire, Philip Johnson, Victor Cruz & Clifton Dalgard

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT *(Year, Month, Day)*	15. PAGE COUNT
Final	FROM TO	2000 May	34

16. SUPPLEMENTAL NOTATION

17. COSATI CODES		
FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*
UH-60, cockpit airbag system, CABS, airbags, supplemental restraints, inadvertent deployment, anthropometry

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*
This study was designed to investigate the possibility of physical interaction between the front seat occupants of a UH-60 Black Hawk helicopter and the proposed UH-60 Cockpit Airbag System (CABS). Five large males (80th - 95th percentile in stature), five mid-size males (40th - 55th percentile in stature), and five small females (5th - 30th percentile in stature) served as volunteer subjects. Subjects were outfitted in representative aircrew clothing and equipment and were seated in the cockpit of a CABS-equipped UH-60. The airbags were slowly inflated to a gauge pressure of 2 pounds per square inch. Afterward, subjects were asked to assume positions ranging from a normal flying position to performing reaches to the overhead and center consoles. At each position, measurements were made between the CABS and specified anatomical regions in order to determine the degree of occupant/airbag interaction. Results show the subjects' chests and outboard arms to have the highest probability of interaction with a deploying CABS; outboard arm interaction was greatest in the left crewstation. Anthropometry was observed to have no consistent effect on the results, possibly due to variations in the subjects' crewseat positions.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Chief, Science Support Center	22b. TELEPHONE *(Include Area Code)* (334) 255-6907 22c. OFFICE SYMBOL MCMR-UAX-SS

DD Form 1473, JUN 86 *Previous editions are obsolete.*

SECURITY CLASSIFICATION OF THIS PAGE

Unclassified

Acknowledgements

This research was funded by the Program Manager, Aircrew Integrated Systems (PM – ACIS), U.S. Army Aviation and Missile Command, Huntsville, Alabama. The authors would like to thank Mr. Wayne Richardson of the U. S. Army Aviation Technical Test Center (USAATTC) for his cooperation and support.

Table of contents

Page

Appendices

List of figures

Table of contents (continued)
List of figures (continued)

Page

List of figures (continued)

List of tables

Introduction

Modern Army helicopters incorporate crashworthy features such as energy absorbing landing gear and seats, self-sealing fuel systems, and harness restraints. In addition, aviators are provided an arsenal of personal protective equipment including flight helmets, survival vests, and fire resistant flight suits and gloves. With these advances has come a reduction in the potential for serious injury in survivable helicopter crashes (Shanahan and Shanahan, 1989; Crowley, 1991).

Even so, helicopter occupants are at high risk of injury during survivable mishaps. Shanahan and Shanahan (1989) have shown that approximately 80 percent of helicopter crash injuries are caused by impacts between the occupants and the aircraft structure. To further reduce the incidence of these impact injuries, the U.S. Army has investigated the possibility of incorporating supplemental airbags into its helicopter fleet. Alem et al (1992) conducted sled tests simulating severe attack helicopter crashes. Data from these tests showed that an airbag in the cockpit of attack helicopters could reduce most indices of head injury severity by as much as 70 percent. Shanahan, Shannon, & Bruckart (1993) projected a 23 percent reduction in injuries and a 50 percent reduction in fatalities during survivable helicopter mishaps through the use of airbags. Based on these U. S. Army Aeromedical Research Laboratory (USAARL) studies (and others), development of a Cockpit Airbag System (CABS) for retrofit into existing aircraft was begun in the mid-1990s. The UH-60 Black Hawk CABS is expected to significantly enhance occupant survival. However, with any airbag system comes the possibility of airbag-induced injury.

There are two main scenarios in which airbag deployment is a safety concern. First, as with automotive airbags, if the occupant is out of ideal body position when the device deploys, injury can result. It is possible that an airbag-induced injury could be the only injury sustained in an aircraft mishap, potentially compromising egress and/or evasion. Second, any airbag system could theoretically deploy when not needed – the so-called “inadvertent deployment.” In the aviation setting, this could occur during normal flight or during mild impacts in which the airbag was unnecessary (e.g., tree or wire strikes, hard landings). In these cases, the potential for injury is compounded with other deployment-related effects such as flight control movement and aviator surprise.

This study was undertaken to determine the possibility of physical interaction between the front seat occupants and the proposed UH-60 CABS. This study of occupant/airbag interaction was intended to provide only a qualitative estimate of the potential for injury to a range of occupant sizes during an inadvertent deployment. It is recognized that further studies will be necessary to adequately define the probability or severity of injury.

Materials and methods

Subjects

Of the fourteen military and one civilian used in the study, five (all of whom were male) had some type of flying experience. One subject was an experienced UH-60 aviator, another was a flight surgeon that had soloed in helicopters, and two subjects were flight medics with flight experience in field units. The lone civilian subject also had experience flying single engine civilian aircraft.

The CABS was designed to provide protection for aviators ranging in size from the 5th percentile (%ile) female to the 95th %ile male (Department of the Army, 1995). To reflect this range of the pilot population, 15 subjects were recruited into 3 groups of varying anthropometric composition, based solely on reported stature. Due to time constraints imposed by the availability of the CABS-equipped UH-60 aircraft, pre-enrollment anthropometric screenings could not be undertaken (a set of measurements was taken on each subject following the completion of the study).

Sample composition

Selecting subjects based on reported stature resulted in a slightly skewed subject population. The subjects were to be stratified into three groups depending on gender and stature: large male (80th – 95th %ile in stature), mid-size male (40th – 55th %ile in stature), and small female (5th – 30th %ile in stature) (Donelson and Gordon, 1990). When the reported stature values were compared with these ranges, each of the potential subjects fit into one of the three demographic groups. However, when the stature values obtained later from our anthropometric measurements were compared with data from Donelson and Gordon (1990), the mid-size male and small female populations actually ranged between the 30th and 55th %iles and the 2nd and 50th %iles, respectively. In addition, one subject initially categorized as a large male was later found to belong in the mid-size male group. This resulted in unequal group sizes: five small females, six mid-size males, and four large males. No additional subjects could be tested due to aircraft unavailability.

The purpose of specifying three subject groups was to ensure that the extremes as well as the more common portion of aviator population were tested. The recruiting process, although imprecise, produced a usable subject population. Figure 1 shows that the large male population tested fell within the desired range for stature. Figures 1 and 2 show that the large males selected for this study represent the upper extreme of the aviator population in each of the other seven anthropometric measurements except bideltoid breadth. Figure 3 shows that the mid-size male population fell within a range of approximately 30th to 55th %ile in stature. While not what was originally desired, this range represents a common portion of aviator population. Although these subjects represented a mid-size male population in stature, Figures 3 and 4 show that for all other anthropometric measurements these subjects were scattered between the 1st to the 98th %iles. For the small female population, none of the subjects fell within the desired range for stature. Four

subjects fell below the 5th %ile in stature and one above the 30th %ile (Figure 5). However, Figures 5 and 6 show that four of the five small female subjects tested represented the 5th %ile or above in sitting height, thumbtip reach, buttock-knee length, functional leg length, and bideltoid breadth. All five female subjects represented the 35th %ile or above and the 20th %ile or above in chest circumference and weight, respectively. The results of the anthropometric measurements are summarized below in Table 1 and tabulated in Appendix A.

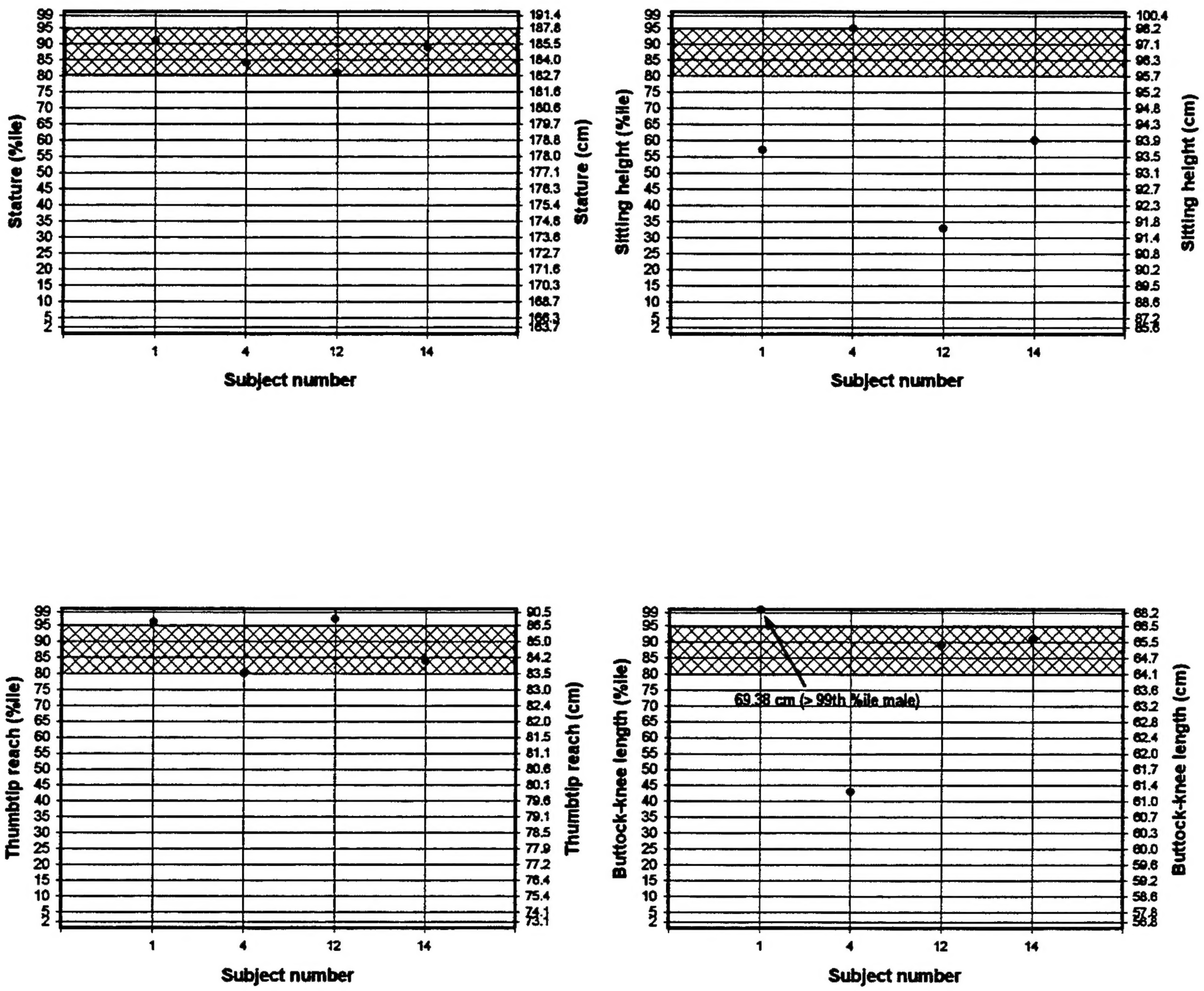


Figure 1. Anthropometric measurements of stature, sitting height, thumbtip reach, and buttock-knee length for the large male subjects. The crosshatched areas show the anthropometric range sought. For large male subjects, this range was between 80th and 95th %iles. Anthropometric ranges taken from Donelson and Gordon (1990).

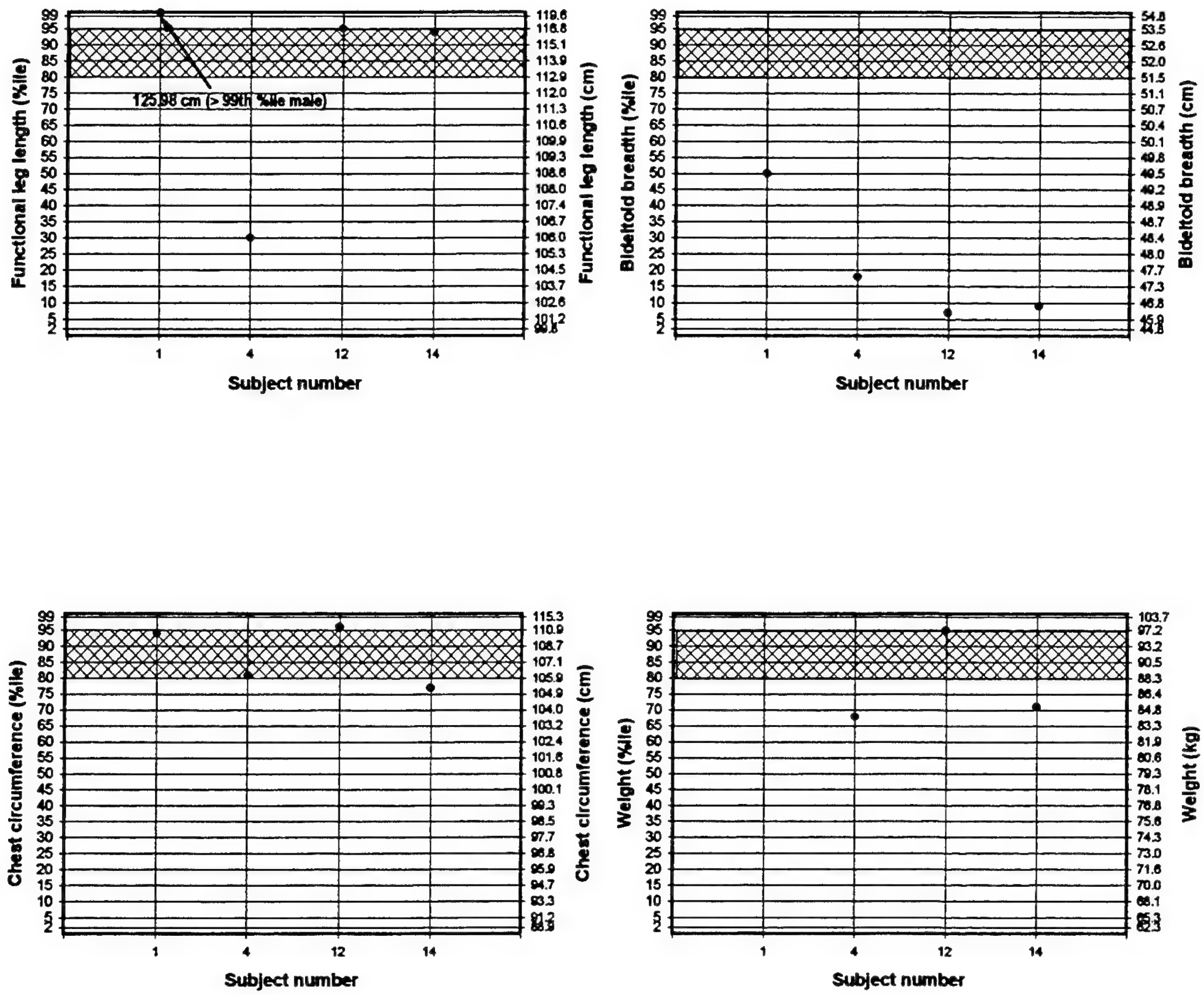


Figure 2. Anthropometric measurements of functional leg length, bideltoid breadth, chest circumference, and weight for the large male subjects. The crosshatched areas show the anthropometric range sought. For large male subjects, this range was between 80^{th} and 95^{th} %iles. Anthropometric ranges taken from Donelson and Gordon (1990).

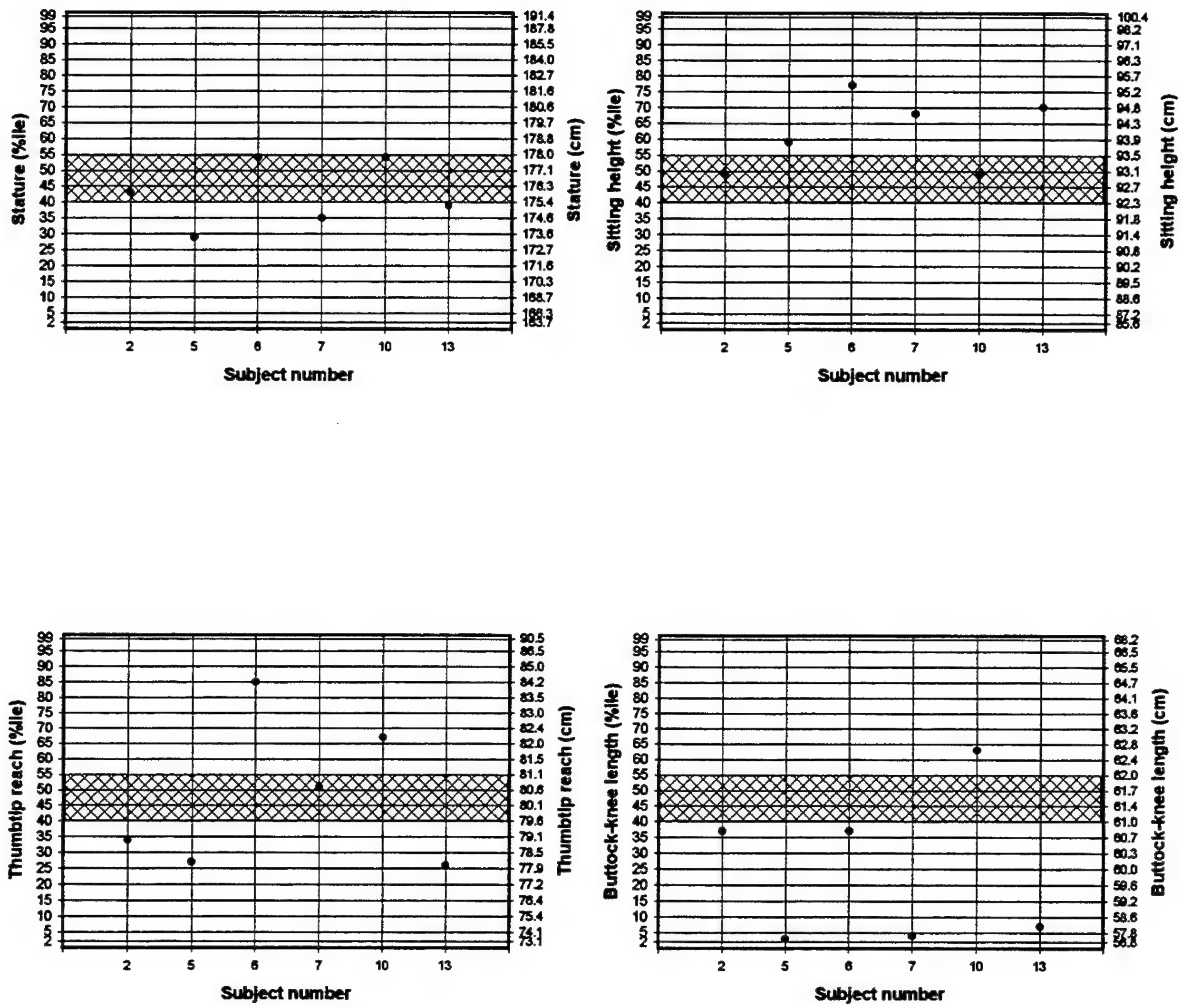


Figure 3. Anthropometric measurements of stature, sitting height, thumbtip reach, and buttock-knee length for the mid-size male subjects. The crosshatched areas show the anthropometric range sought. For mid-size male subjects, this range was between 40th and 55th %iles. Anthropometric ranges taken from Donelson and Gordon (1990).

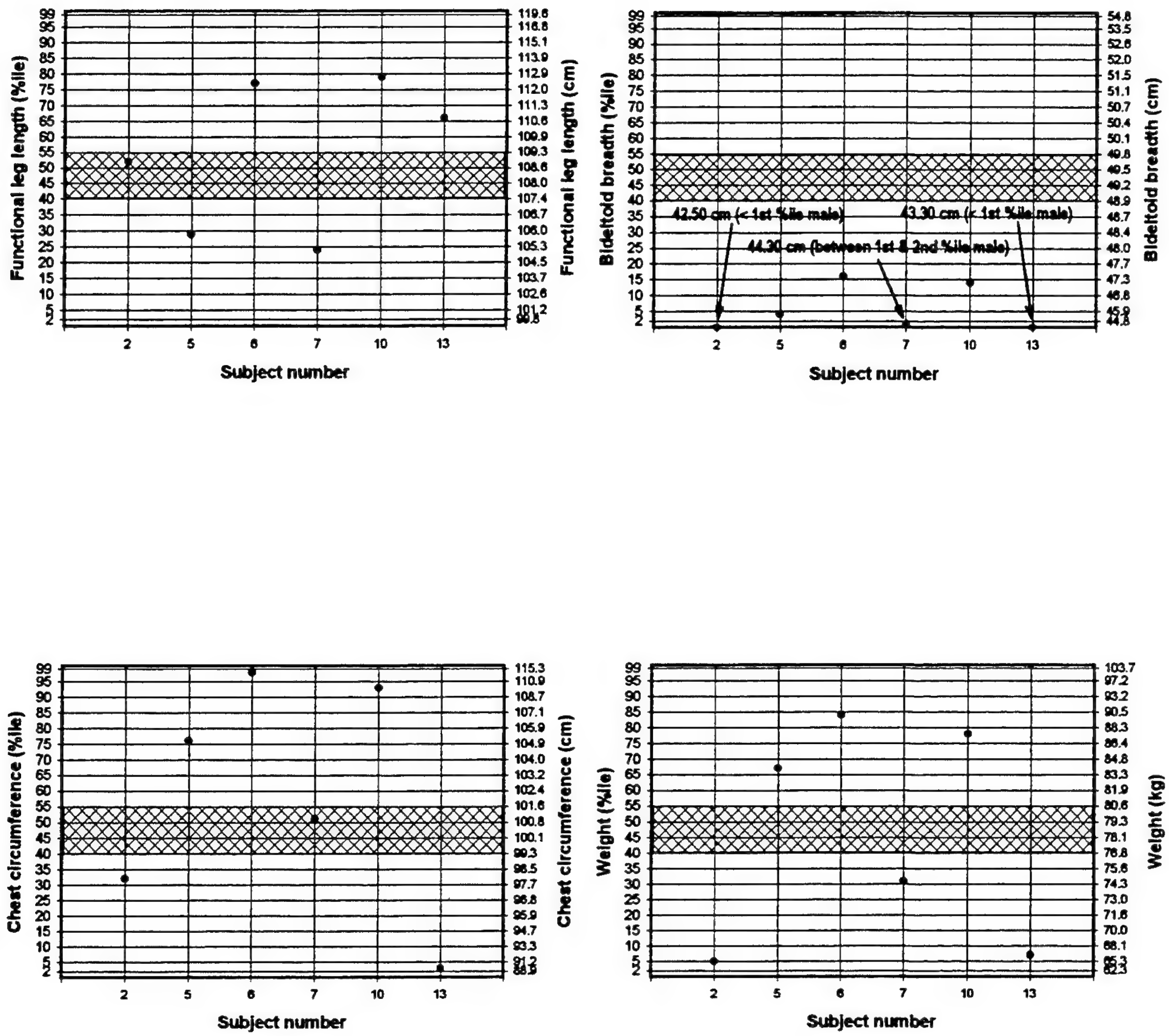


Figure 4. Anthropometric measurements of functional leg length, bideltoid breadth, chest circumference, and weight for the mid-size male subjects. The crosshatched areas show the anthropometric range sought. For mid-size male subjects, this range was between 40th and 55th %iles. Anthropometric ranges taken from Donelson and Gordon (1990).

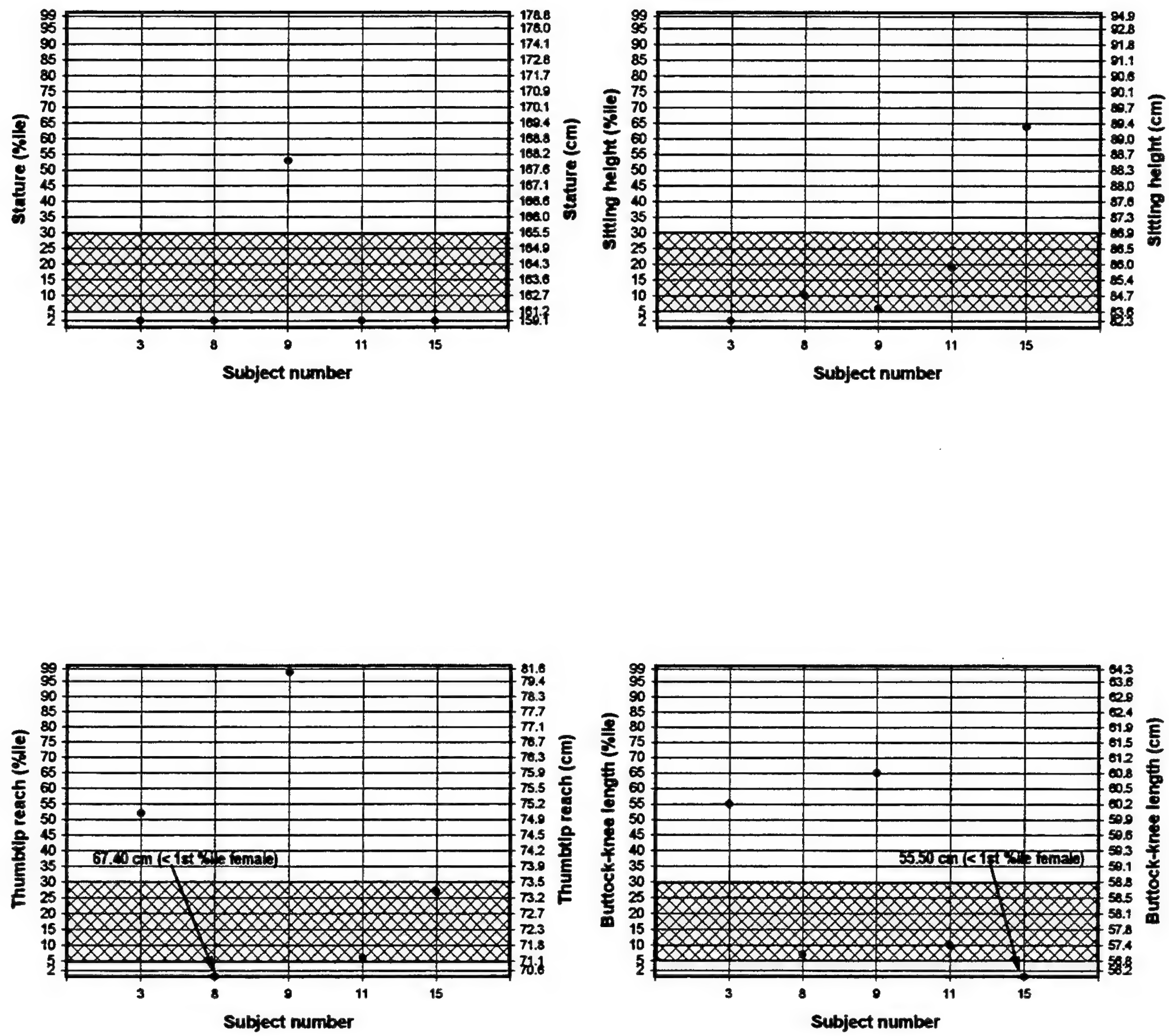


Figure 5. Anthropometric measurements of stature, sitting height, thumbtip reach, and buttock-knee length for the small female subjects. The crosshatched areas show the anthropometric range sought. For small female subjects, this range was between 5th and 30th %iles. Anthropometric ranges taken from Donelson and Gordon (1990).

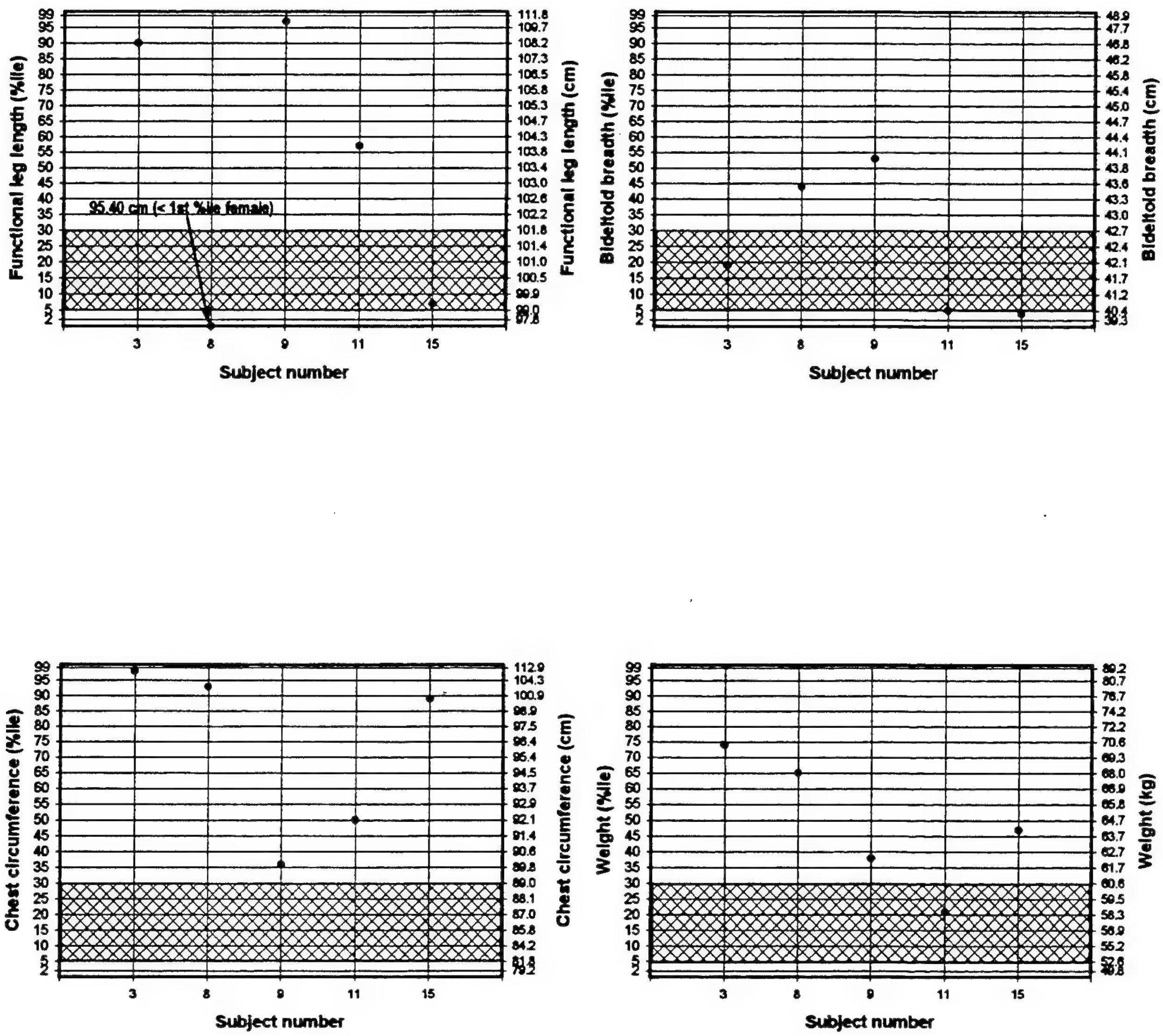


Figure 6. Anthropometric measurements of functional leg length, bideltoid breadth, chest circumference, and weight for the small female subjects. The crosshatched areas show the anthropometric range sought. For small female subjects, this range was between 5^{th} and 30^{th} %iles. Anthropometric ranges taken from Donelson and Gordon (1990).

Table 1.
Mean values and standard deviations of anthropometric measurements for the three anthropometric study groups.

Anthropometric measurements	Large male		Mid-size male		Female		Overall	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
Stature (cm)	184.4	1.4	175.8	1.8	161.6	3.6	173.4	9.6
Sitting height (cm)	94.3	2.7	94.1	1.0	85.1	2.8	91.2	4.9
Thumbtip reach (cm)	85.5	2.0	80.4	2.5	73.5	4.9	79.5	5.8
Buttock-knee length (cm)	65.4	3.3	59.5	2.2	58.2	2.2	60.6	3.8
Functional leg length (cm)	116.3	8.2	109.3	3.2	103.5	6.3	109.3	7.4
Bideltoid breadth (cm)	47.5	1.5	45.1	2.0	42.0	1.8	44.7	2.8
Chest circumference (cm)	108.4	3.2	103.0	8.6	98.7	7.5	103.0	7.7
Weight (kg)	88.7	7.0	78.0	10.8	64.7	4.7	75.5	12.1

Equipment

This study was conducted using a UH-60 aircraft (tail number 23983) assigned to the U.S. Army Aviation Technical Test Center (USAATTC), Cairns Army Airfield, Alabama. This aircraft was equipped with a full UH-60 production CABS. The airbag module covers had been opened and the airbags deployed during a series of actual deployments using live gas generators. The gas generators used during the live deployments had been removed and replaced with fittings enabling the airbags to be inflated using compressed air.

For certain measurements, a previously designed jig was used to position the subjects in the design eye point (DEP) of the right crewstation (Gordon and Licina, 1999). The curved piece of metal at the end of the pyramid-shaped structure marked the DEP (Figure 7).

During all trials, subjects were dressed in representative aircrew clothing and equipment. Either flight suits or battle dress uniforms (BDUs) and boots were allowed. BDUs were deemed acceptable since the Aviation BDU (ABDU) is the Army's new standard aircrew attire. Each subject was also equipped with an SRU-21/P survival vest and an SPH-4B flight helmet fitted with an Aviator Night Vision Imaging System (ANVIS) night vision goggle (NVG) mount. Fitting procedures for the SPH-4B were cursory, as the helmet served no protective function during these trials.

Experimental design

This study was designed to determine which portions of an aviator's anatomy are at potential risk during an inadvertent deployment. To facilitate this, subjects were seated in both the right and left crewseats. While seated in each crewseat, the subjects assumed positions ranging from normal flying posture to reaching for flight controls located on the overhead and

center consoles (Table 2). At each position, measurements were taken between the airbags and specified anatomical regions (Table 3) in order to determine the degree of occupant/airbag interaction. Throughout these trials, the cyclic was left in its neutral position, and the collective was raised to 41 centimeters (cm) (16 inches) above the aircraft floor, corresponding to an engine torque setting of approximately 52 percent.

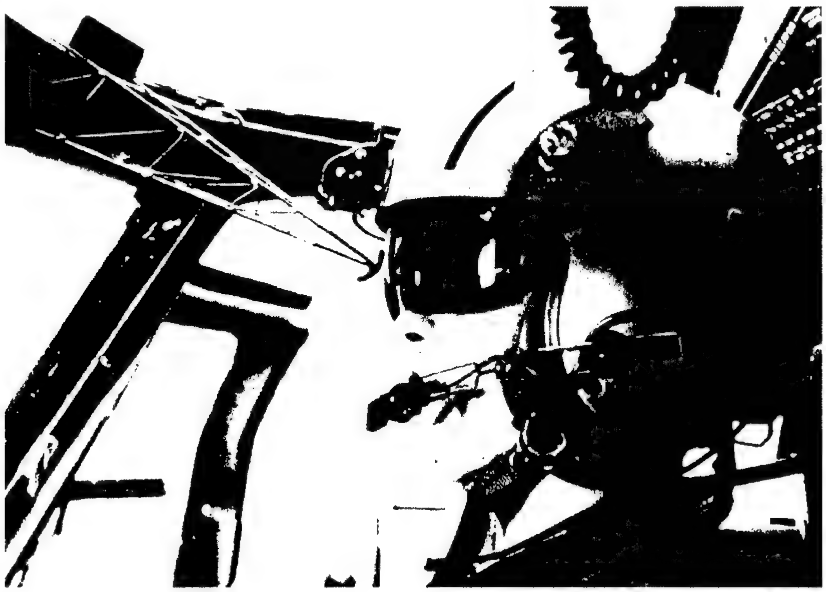


Figure 7. Design eye point jig.

Table 2.
Occupant positions tested.

Position	Description
1	Normal flying posture with feet on pedals – pedals neutral, hands on controls – cyclic neutral, collective raised to 41 cm above the aircraft floor
2	Resting outboard hand on overhead handhold
3	Reaching up for the power control levers with the inboard hand
4	Reaching for the tail rotor servo switch located on the center console with the inboard hand
5	Writing on a kneeboard strapped to the outboard leg using outboard hand
6	Subject's head rotated 90° as if clearing aircraft out the side window without NVGs
7	Leaning forward as if looking over the aircraft's nose
8	Design eye point

The trials were begun with the subject seated in the right crewseat and strapped in using the existing five-point restraint. The right forward and lateral airbags were inflated using compressed air to a gauge pressure of 2 pounds per square inch (psi). The subjects were then positioned in a normal flying posture. Subjects with aviation experience were asked to move their seats to their customary flying position. Subjects with no prior aviation experience were

shown a typical aviator posture (i.e., back slightly hunched, left hand grasping the collective, right hand holding the cyclic with the right forearm resting on the right thigh), and asked to move their seats to a comfortable position. The complete listing of all occupant positions tested is shown in Table 2.

Table 3.
Anatomic regions used for measurements.

Region	Description
1	Face
2	Chest
3	Right leg
4	Left leg
5	Lower outboard arm
6	Upper outboard arm/shoulder
7	Lower inboard arm
8	Upper inboard arm/shoulder
9	Closest point on the NVGs.

Positions 2 through 7 were all initiated from the normal flying position. After completing a set of measurements in each position, the subjects were brought back to the normal flying position, and the next occupant position was described to the subjects. This was done to ensure that occupant's motions all started from a common posture.

At each occupant position, measurements were taken to quantify the amount of interaction between the subject and the airbags. The measurements, which were recorded in inches and later converted to centimeters for analysis, consisted of the clearance (expressed as a positive number) or degree of contact (expressed as a negative number) between the airbag and the closest point at nine anatomic regions listed in Table 3. The degree of contact was measured by moving the subject away from the area of contact until contact was broken with the airbag. The distance required to break contact was recorded as a negative number and taken as a measure of the magnitude of the contact. In addition, the location of the point within each anatomic region to which the measurements were made was recorded. Only measurements unique to the specific occupant position were recorded (i.e., the position of the subjects' legs did not change between the normal flying position and any of the other positions. Thus, the clearance between the legs and the frontal airbag was taken once.).

After taking measurements in each occupant position with the subject seated in the right crewstation, the subject was transferred to the left crewseat and certain measurements were repeated. Emphasis was placed on obtaining measurements between the subjects' outboard arms and the lateral airbags. These regions of the body were of interest due to the fact that the outboard arm in the left seat is drawn closer to the lateral airbag by elevation of the collective. Outboard arm clearances were measured between the arm and the lateral airbag while the subjects were in the normal flying position, reaching for the power control levers and the tail

rotor servo switch, and looking over the aircraft's nose. The DEP position was not repeated since the DEP jig was designed only for use in the right crewstation. The other three positions (writing on the kneeboard, resting the outboard hand on the overhead handhold, and rotating the head 90° as if clearing the aircraft) would not vary much from the right crewseat conditions, and were not repeated in the left crewseat.

The assumption was made that occupants within 6 cm of the statically inflated forward airbag would make contact with CABS during inflation. Figure 8 shows the dynamic overshoot of the forward airbag during deployment. Analysis of high-speed videos has shown that, during deployment (Figure 8, left), the leading edge of the airbag extends 6 cm beyond its fully inflated position (Figure 8, right). If the manikin were not in the path of the airbag, it is conceivable that the forward airbag's dynamic overshoot would exceed 6 cm. However, this could not be ascertained from the available high-speed video images.

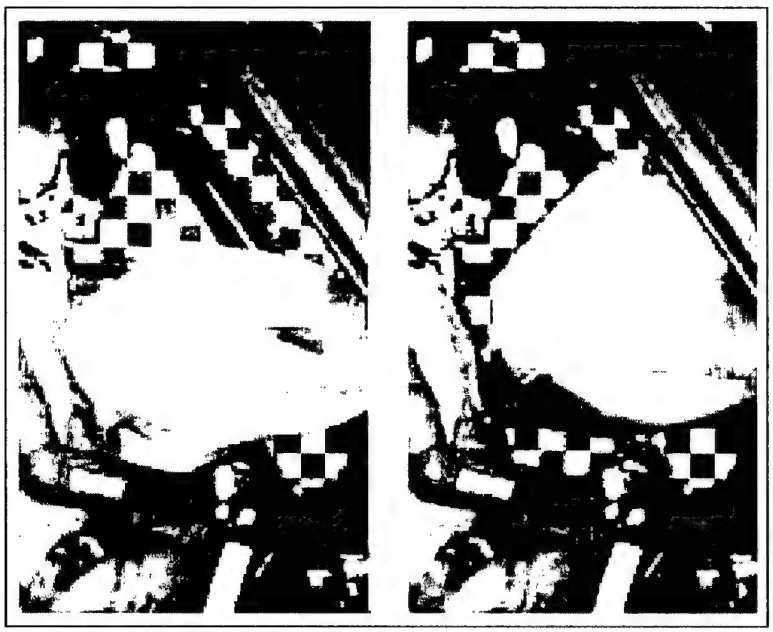


Figure 8. Dynamic overshoot of the forward airbag during deployment.

Results

General

Table 4 shows the percentage of subjects with whom the right-side forward airbag made direct contact or would likely make contact during deployment. Tables 5 and 6 show the percentage of subjects that came into direct contact with the right- and left-side lateral airbags,

respectively. Due to dynamic overshoot of the forward airbag during deployment, the assumption was that anatomic regions within 6 cm of the forward airbag would make at least "brushing" contact. Therefore, the anatomic regions shown in Table 4 to be experiencing "brushing" contact includes those with a clearance from the forward airbag of between 0 cm and 6 cm. As no assumptions were made regarding dynamic overshoot of the lateral airbags, "brushing" contact was characterized by a clearance of 0 cm between airbag and the anatomic region (Tables 5 and 6). In Tables 4 through 6, "pressing" contact was characterized by a clearance of less than 0 cm. If a measurement was not taken between an anatomic region and the airbags, it is represented in Tables 4 through 6 by "--." These results are depicted graphically in Appendix B. Figure 9 represents the interaction between a specific anatomic region and either the forward or lateral airbags.

Table 4.
Percentage of subjects in contact with right-side forward airbag.
Values rounded to nearest whole percentage.

Position	Degree of contact †	Face	Chest	Lower out. arm	Upper out. arm	Lower in. arm	Upper in. arm	Left leg	Right leg	NVGs
DEP	Brushing	0	60	--	--	--	--	40	0	0
	Pressing	0	40	--	--	--	--	0	0	0
Flying position	Brushing	0	60	64	0	0	0	33	0	7
	Pressing	0	27	0	0	0	0	0	0	0
Handhold	Brushing	0	60	73	87	--	--	--	--	--
	Pressing	0	27	27	13	--	--	--	--	--
Power levers	Brushing	0	60	64	0	0	0	--	--	0
	Pressing	0	27	0	0	0	0	--	--	0
Servo switch	Brushing	13	64	86	8	73	20	--	--	40
	Pressing	0	36	0	0	0	0	--	--	7
Kneeboard	Brushing	13	60	57	0	--	--	--	--	--
	Pressing	0	27	0	0	--	--	--	--	--
Head 90°	Brushing	0	54	--	0	--	--	--	-	0
	Pressing	0	38	--	0	--	--	--	--	0
Over nose	Brushing	67	33	--	0	--	0	--	--	47
	Pressing	0	67	--	0	--	0	--	--	0

† "Brushing" contact was characterized by a clearance between the anatomic region and the forward airbag of between 0 cm and 6 cm. "Pressing" contact was characterized by a clearance of less than 0 cm. If a measurement was not taken between an anatomic region and the airbags, it is represented by "--."

Table 5.
Percentage of subjects in contact with right-side lateral airbag.
Values rounded to nearest whole percentage.

Position	Degree of contact †	Face	Chest	Lower out. arm	Upper out. arm	Lower in. arm	Upper in. arm	Left leg	Right leg	NVGs
DEP	Brushing	0	--	--	--	--	--	--	47	0
	Pressing	0	--	--	--	--	--	--	13	0
Flying position	Brushing	0	--	27	13	--	--	--	50	0
	Pressing	0	--	7	73	--	--	--	14	0
Handhold	Brushing	0	--	40	40	--	--	--	--	--
	Pressing	0	--	0	60	--	--	--	--	--
Power levers	Brushing	0	--	27	13	--	--	--	--	0
	Pressing	0	--	7	60	--	--	--	--	0
Servo switch	Brushing	0	--	13	13	--	--	--	--	0
	Pressing	0	--	7	27	--	--	--	--	0
Kneeboard	Brushing	0	--	47	7	--	--	--	--	--
	Pressing	0	--	20	80	--	--	--	--	--
Head 90°	Brushing	0	--	--	21	--	--	--	--	0
	Pressing	0	--	--	29	--	--	--	--	0
Over nose	Brushing	0	--	--	8	--	--	--	--	0
	Pressing	0	--	--	92	--	--	--	--	0

† "Brushing" contact was characterized by a clearance of 0 cm between the lateral airbag and the anatomic region. "Pressing" contact was characterized by a clearance of less than 0 cm. If a measurement was not taken between an anatomic region and the airbags, it is represented by "--."

Table 6.
Percentage of subjects in contact with left-side lateral airbag.
Values rounded to nearest whole percentage.

Position	Degree of contact †	Face	Chest	Lower out. arm	Upper out. arm	Lower in. arm	Upper in. arm	Left leg	Right leg	NVGs
DEP	Brushing	--	--	--	--	--	--	--	--	--
	Pressing	--	--	--	--	--	--	--	--	--
Flying position	Brushing	--	--	0	0	--	--	--	--	--
	Pressing	--	--	100	93	--	--	--	--	--
Handhold	Brushing	--	--	--	--	--	--	--	--	--
	Pressing	--	--	--	--	--	--	--	--	--
Power levers	Brushing	--	--	0	0	--	--	--	--	--
	Pressing	--	--	100	85	--	--	--	--	--
Servo switch	Brushing	--	--	13	20	--	--	--	--	--
	Pressing	--	--	80	33	--	--	--	--	--
Kneeboard	Brushing	--	--	--	--	--	--	--	--	--
	Pressing	--	--	--	--	--	--	--	--	--
Head 90°	Brushing	--	--	--	--	--	--	--	--	--
	Pressing	--	--	--	--	--	--	--	--	--
Over nose	Brushing	--	--	--	7	--	--	--	--	--
	Pressing	--	--	--	87	--	--	--	--	--

† "Brushing" contact was characterized by a clearance of 0 cm between the lateral airbag and the anatomic region. "Pressing" contact was characterized by a clearance of less than 0 cm. If a measurement was not taken between an anatomic region and the airbags, it is represented by "--."

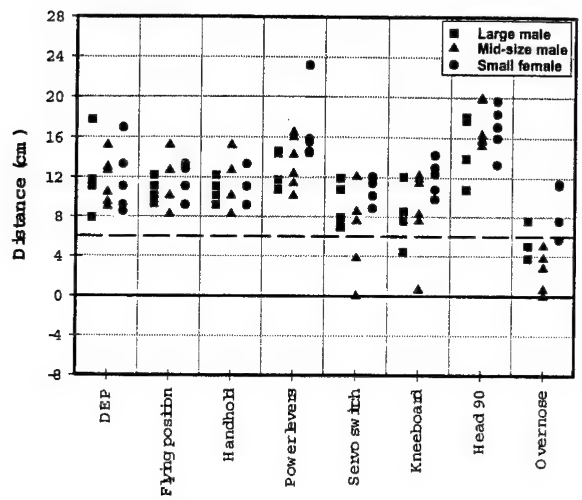


Figure 9. Measurements of clearance/contact between right-side forward airbag and subjects' faces. Positive values (shown as symbols located above the dark horizontal line at 0 cm) characterize clearance. Distances less than or equal to 0 cm (shown as symbols located on or below the dark horizontal line at 0 cm) represent contact. A distance of 0 cm corresponds to brushing contact, while larger negative numbers indicate increasing contact severity. The dashed horizontal line represents the 6 cm distance from the forward airbag taken to represent probable contact due to dynamic overshoot.

Forward airbag interaction

Subjects' faces were drawn closer to the forward airbag when reaching for the tail rotor servo switch, writing on the kneeboard, and looking over the aircraft's nose (Table 4). These positions required the subject to lean forward from his normal flying position, lessening the clearance between the face and forward airbag (Figure 10). In each of these positions, it was the mid-size male subjects that came closest to the airbag (Figure 9). While reaching for the tail rotor servo switch, one mid-size male subject came into contact with the forward airbag, and two mid-size male subjects made contact with the forward airbag when looking over the aircraft's nose. In each of these cases, contact was made with the chin and was characterized as brushing contact (Figure 11).

The body region most frequently contacted by the forward airbag was the chest (Table 4). Of the subjects who did not make direct contact (either brushing or pressing) with the forward airbag, all but two were within 6 cm of it (Figure 12). These subjects (one mid-size male and one small female) sat with their seats as far aft as possible.

The specific areas of the chest that came into contact with the forward airbag were consistent across subject groups. The most frequent areas were the sternum and the right rib cage in the area of the first aid kit pocket on the survival vest. For the large male subjects, 37.5 percent of the measurements were made from the first aid pocket while 28.1 percent were made

from the sternum. For the mid-size male population, 41.7 percent of measurements were made from the first aid pocket and 31.3 percent from the sternum. Measurements taken from the first aid pocket and sternum accounted for 47.5 percent and 10 percent of the total number of chest-airbag measurements in the small female group.

Figure 10. Illustration of subject position when reaching for the tail rotor servo switch.

Figure 11. Brushing contact between chin and right-side forward airbag. Subject is looking over the aircraft's nose.

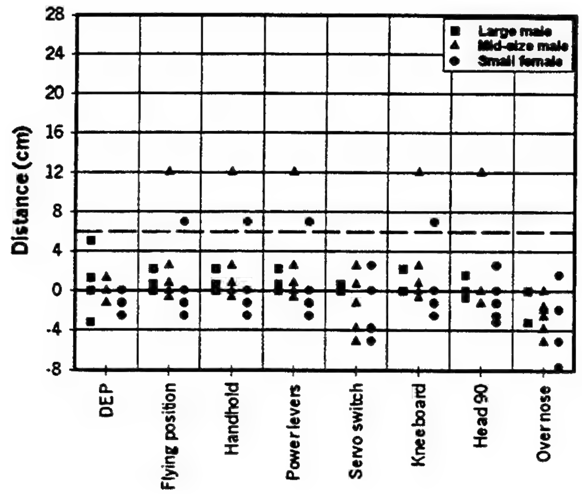


Figure 12. Measurements of clearance/contact between right-side forward airbag and subjects' chests. Distances greater than 0 cm indicate clearance. Distances less than or equal to 0 cm indicate contact.

The degree of contact with the forward airbag varied with subject type. The large male population experienced the lightest amount of contact while the small females experienced the most severe. Figure 13 shows that subjects whose seats were positioned further forward experienced a higher degree of contact ($r = 0.685$, $p = 0.0047$) than those whose sat further aft. In the normal flying position, we observed that the small female subjects generally positioned their seats closest to the forward airbag, followed by the mid-size and large males.

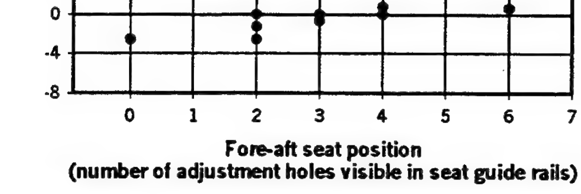


Figure 13. Distance between right-side forward airbag and subjects' chests as a function of fore-aft seat position. Seat position is given in the number of adjustment holes visible in the fore-aft seat guide rail. The larger the number of visible adjustment holes, the further aft the seat is positioned. Distances greater than 0 cm indicate clearance. Distances less than or equal to 0 cm indicate contact.

The interactions between the forward airbag and the NVGs are shown in Figure 14. In most occupant positions, the NVGs remained well away from the forward airbag. NVGs were drawn closer to the forward airbag when the subjects reached for the tail rotor servo switch or looked over the aircraft's nose. As stated previously, these positions required the subject to lean forward in order to attain the desired position.

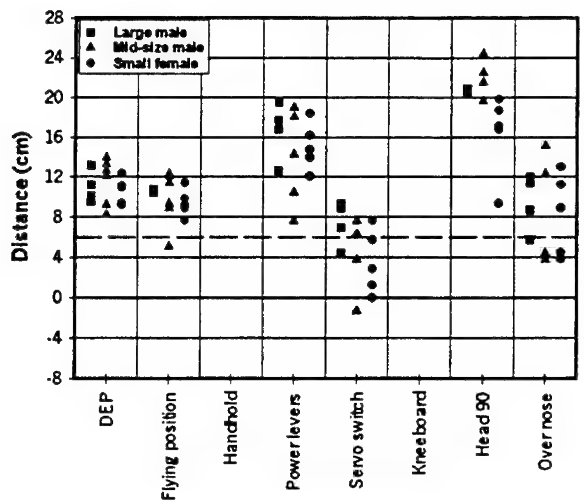


Figure 14. Measurements of clearance/contact between right-side forward airbag and subjects' NVGs. Distances greater than 0 cm indicate clearance. Distances less than or equal to 0 cm indicate contact.

Two subjects' NVGs made contact with the forward airbag while reaching for the tail rotor servo switch (Table 4 and Figure 14). Of these two subjects (one mid-size male and one small female), the mid-size male had the most significant interaction (Figure 15) (this mid-size male subject positioned his seat fully aft). In both instances of contact, it was the anterior aspect of the objective lens that touched the forward airbag.

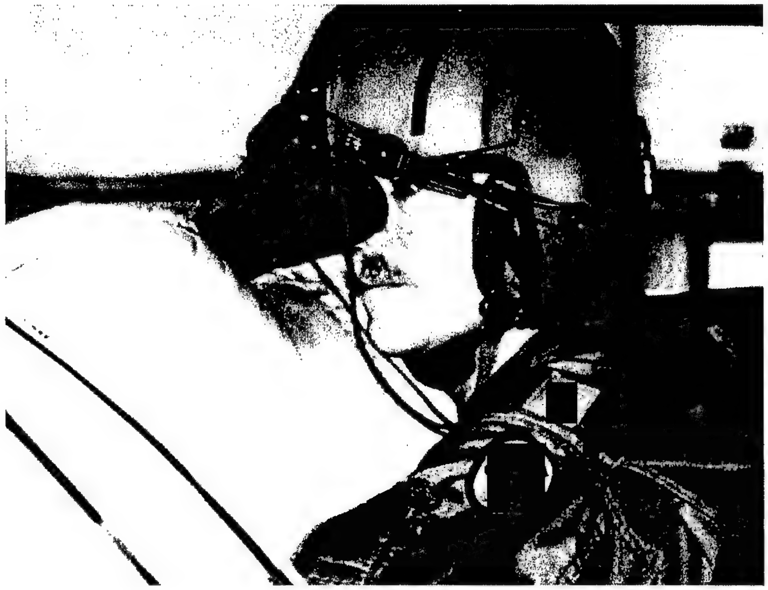


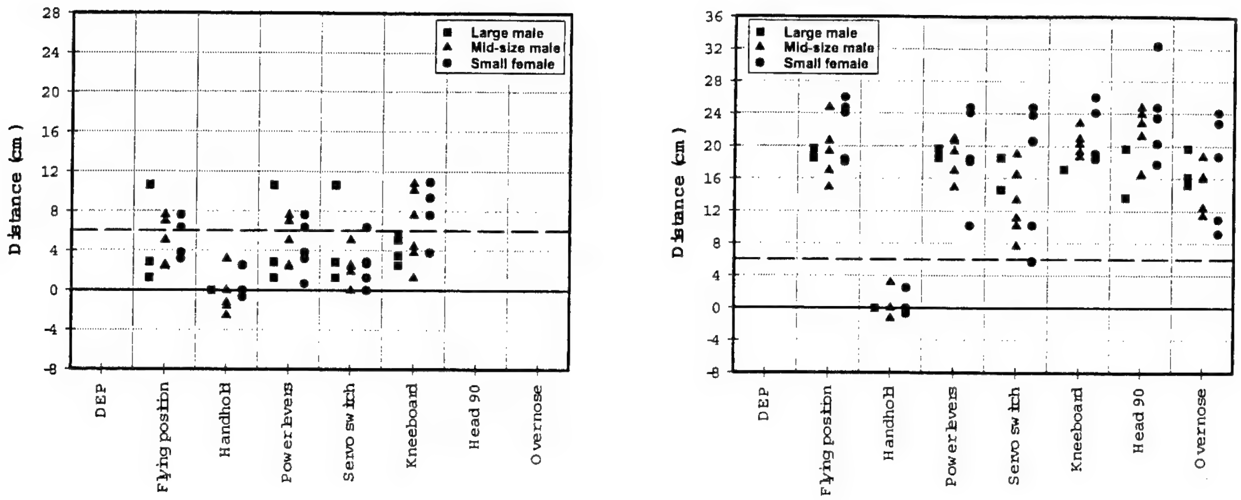
Figure 15. Contact between the NVGs and right-side forward airbag.

Subjects' outboard arms came into contact with the forward airbag most frequently when subjects were resting their outboard hands on the overhead handhold (Figure 16). Typically, contact with the lower outboard arm occurred between the mid-forearm and the elbow, and with the upper outboard arm between the medial elbow and the biceps.

There were other instances of lower arm contact with the forward airbag. Brushing contact was made with the forearms of two subjects (one mid-size male and one small female) when reaching for the tail rotor servo switch (Table 4). The areas of the lower outboard arms most frequently contacting the forward airbag were outboard hands (84 percent), forearms (8 percent), and wrists (5 percent). When holding the cyclic, hands and wrists were below the deploying airbag and shielded from direct contact by the upper portion of the cyclic.

Lateral airbag interaction

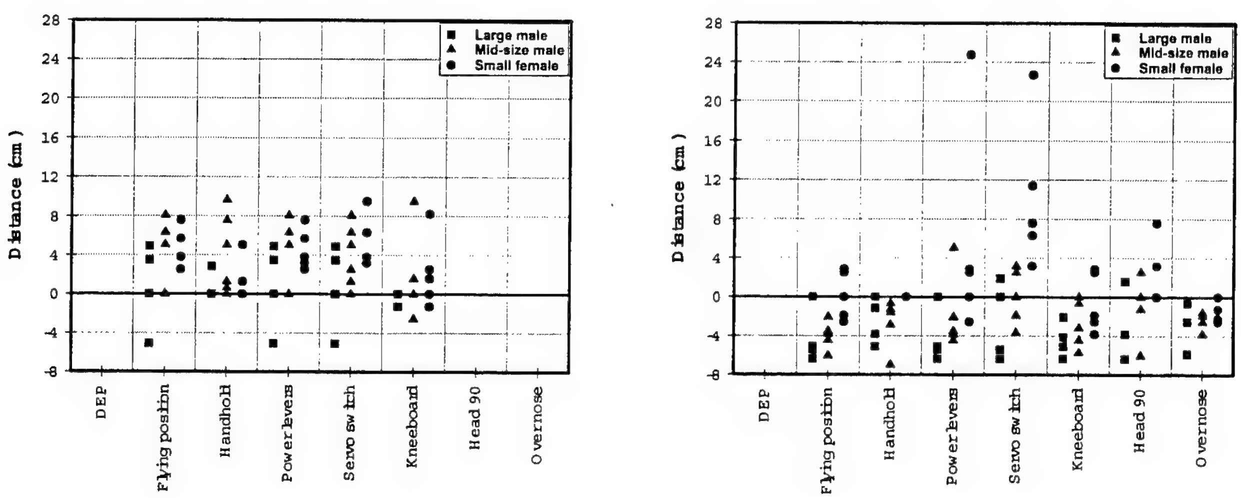
Subjects' outboard arms interacted significantly with the lateral airbags in both crewstations (Tables 5 and 6, and Figures 17 and 18). The greatest degree of interaction was noted in the left crewstation.



(a) Lower outboard arm

(b) Upper outboard arm

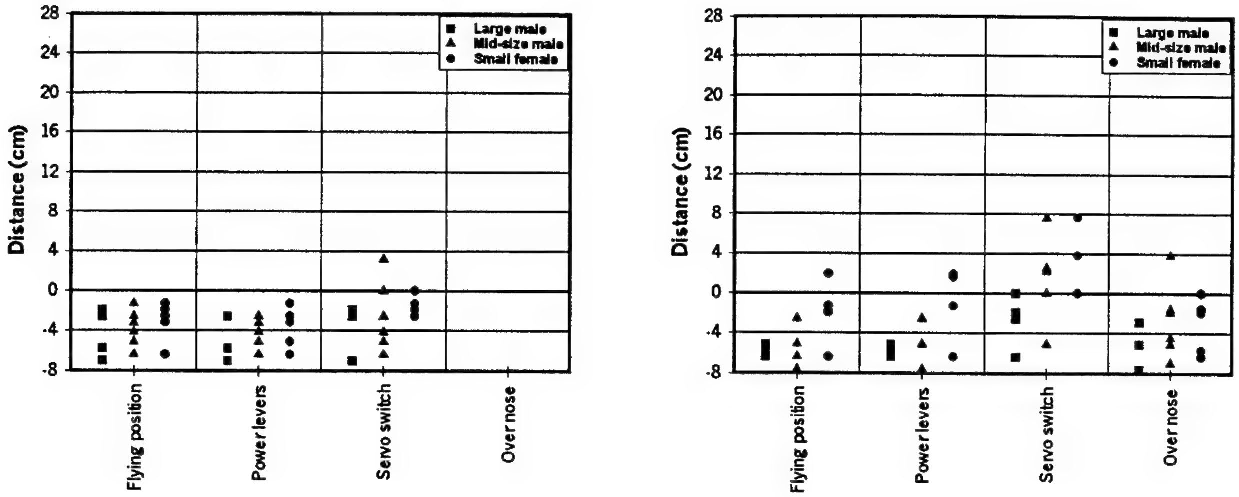
Figure 16. Measurements of clearance/contact between right-side forward airbag and subjects' outboard arms. Distances greater than 0 cm indicate clearance. Distances less than or equal to 0 cm indicate contact.



(a) Lower outboard arm

(b) Upper outboard arm

Figure 17. Measurements of clearance/contact between right-side lateral airbag and subjects' outboard arms. Distances greater than 0 cm indicate clearance. Distances less than or equal to 0 cm indicate contact.



(a) Lower outboard arm (b) Upper outboard arm

Figure 18. Measurements of clearance/contact between left-side lateral airbag and subjects' outboard arms. Distances greater than 0 cm indicate clearance. Distances less than or equal to 0 cm indicate contact.

Lower arms

In the right crewstation, the subjects' lower outboard arms are drawn away from the lateral airbag due to the central position of the cyclic, but the position of the collective in the left crewstation places the subjects' lower outboard arms directly in the path of the lateral airbag. In many cases, subjects' wrists were pinched between the left-side lateral airbag and the outer edge of the armored seat pan.

Upper arms

Members of all subject groups experienced pressing contact with the right- and left-side lateral airbags. Unlike the lower outboard arm instance, the severity of upper outboard arm contact remained constant between the crewstations (Figures 17b and 18b). In the right crewstation, the lateral airbag module cover made contact with the upper outboard arm of two large male subjects, one mid-size male, and one small female subject. In the left crewstation, several subjects complained of their upper arms being painfully pinned between the seat back and the lateral airbag module cover (Figure 19). To reduce subject discomfort, the investigators reduced airbag pressure to a tolerable level when complaints were voiced, allowing data collection to continue.

Participant comments

The UH-60 aviator tested in this study identified additional positions that he felt were vulnerable in the event of an inadvertent deployment. Both of these positions involved reaches

to the center of the forward console. The first reach was to the master caution reset button located to the upper right portion of the forward instrument panel just below the glare shield. The second was to the adjustment knob on the magnetic compass. In both these reaches, an aviator's forearm would be located immediately above the cyclic. The subject expressed concern that during an inadvertent deployment, the forward airbag would drive the forearm down onto the top of the cyclic, possibly breaking the forearm and incapacitating the aviator.

Figure 19. Example of upper extremity pinned between left-side lateral airbag module cover and seat back. Subject shown is a mid-size male with hands on flight controls.

Discussion

General

This study was intended to provide a qualitative estimate of the injury potential associated with a prototype helicopter airbag system, and should not be taken as evidence of injury in a dynamic deployment scenario. However, the results of this study were used to design live deployment studies using anthropomorphic test devices. The quantitative results of those studies appear to confirm the estimates contained in this paper (McEntire, in press).

Although the genesis of this study related to inadvertent deployment (i.e. during flight, with no triggering impact), the results suggest that airbag interaction with the upper extremity may be problematic even in crash scenarios. While it is recognized that airbag deployments are violent events and some injury potential is inevitable (e.g. when occupants are out of position), these must be minimized. A severe upper extremity injury, for example, could impede egress or diminish the aviator's ability to escape and evade – ultimately affecting survival. The degree of upper arm/elbow contact during our static testing suggests that considerable injury could result from deployments, even in normal flying positions.

Study limitations

As discussed above, a limitation to this brief study relates to the anthropometric range of the subjects. By the time it was discovered that self-reported stature was unreliable, it was not possible to recruit additional subjects. As a consequence, the three study groups were of slightly different size, and represented a larger span of the population than desired. An additional factor that was anticipated and an inevitable sequelae of the study design is the large spread in the other anthropometric measures. Nonetheless, the three sample groups did capture different subpopulations of Army aviation, and useful insight into aircrew/airbag interaction was obtained. The lack of aviation experience on the part of several subjects is a potential limitation in that their 'flying position' was not based on actual knowledge. However, the major findings of this preliminary study were robust and occurred across the sample, regardless of aviation experience.

Conclusions

The risk of aircrew contact with this UH-60 prototype CABS in an inadvertent deployment scenario is greatest for the chest and outboard arm regions. The degree of contact was greatest for the outboard arm when seated in the left crewstation.

The risk to the upper extremity is of particular concern because significant contact occurred during normal operation of the collective control. The chest/face contact tended to occur during reaching positions that occupy a smaller proportion of flying activities. The potential for injury to the other anatomic regions does exist. However, this evidence of contact should not be taken as assurance of injury – the behavior of a deploying airbag is different from one that is statically inflated.

Anthropometry had no consistent effect on the results. It is likely that the effect of anthropometry may have been affected by variations in crewseat position.

Recommendations

Further work should be performed to evaluate the risk and severity of injury to these regions. To do so, it is recommended that actual in-aircraft airbag deployments be performed using anthropomorphic test devices as human surrogates. These studies are underway at USAARL.

If future studies of this nature (i.e., static deployments) are undertaken, the subject population should be comprised of aviators. This recommendation is based on the fact that the aviators are the most familiar with flying positions, and can represent actual flying behaviors. Also, the anthropometric variables of interest should be carefully measured prior to enrollment; self-report should not be the sole means of subject screening.

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Appendix A.

Subject anthropometric data.

Table.

Subject population anthropometric data

Subject number	Stature (cm)	Sitting height (cm)	Thumbtip reach (cm)	Buttock-knee length (cm)	Functional leg length (cm)	Bideltoid breadth (cm)	Chest circumference (cm)	Weight (kg)
1	186.10	93.68	86.90	69.38	125.98	49.50	110.50	†
2	175.90	93.00	79.00	60.80	108.90	42.50	98.10	65.30
3	160.53	81.98	75.00	60.18	108.18	42.00	108.00	70.37
4	183.70	98.10	83.50	61.20	106.00	47.50	106.10	84.11
5	173.40	93.78	78.20	57.28	105.88	45.70	105.20	83.80
6	177.80	95.40	84.20	60.80	112.40	47.40	113.98	90.14
7	174.63	94.60	80.70	57.48	105.18	44.30	100.97	74.50
8	160.02	84.60	67.40	57.00	95.40	43.50	102.80	68.11
9	167.96	83.70	80.60	60.80	110.70	44.00	90.00	62.39
10	177.80	93.00	82.20	62.60	112.80	47.20	109.86	87.69
11	160.66	85.90	71.30	57.40	104.00	40.40	92.20	58.58
12	182.88	91.60	87.50	65.30	117.00	46.30	111.76	96.81
13	175.26	94.78	78.00	58.08	110.68	43.30	89.85	66.47
14	185.10	93.88	84.00	65.68	116.38	46.50	105.41	85.16
15	158.75	89.30	73.30	55.50	99.40	40.00	100.33	64.16

† Subject volunteered for study while visiting friends stationed at Fort Rucker. Subject departed from Fort Rucker prior to the realization that the measurement of weight had not been collected.

Appendix B.

Aircrew/airbag interaction data.

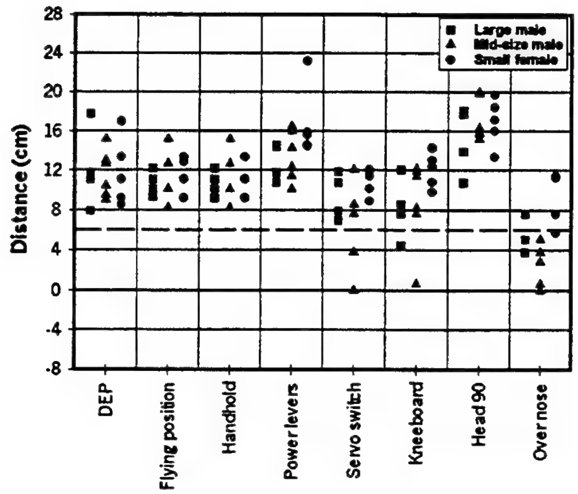


Figure B-1. Clearance between right-side forward airbag and subjects' faces. Positive distances characterize clearance. Distances less than or equal to 0 cm represent contact. A distance of 0 cm corresponds to brushing contact, while larger negative numbers indicate increasing contact severity. The dashed horizontal line represents the 6 cm distance from the forward airbag taken to represent probable contact due to dynamic overshoot.

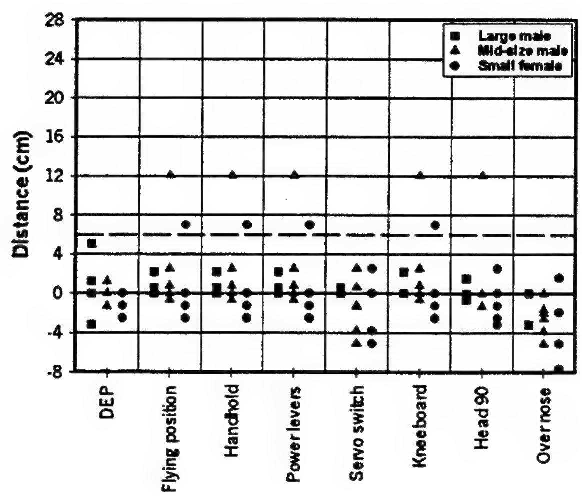


Figure B-2. Clearance between right-side forward airbag and subjects' chests. Positive distances characterize clearance. Distances less than or equal to 0 cm represent contact. A distance of 0 cm corresponds to brushing contact, while larger negative numbers indicate increasing contact severity. The dashed horizontal line represents the 6 cm distance from the forward airbag taken to represent probable contact due to dynamic overshoot.

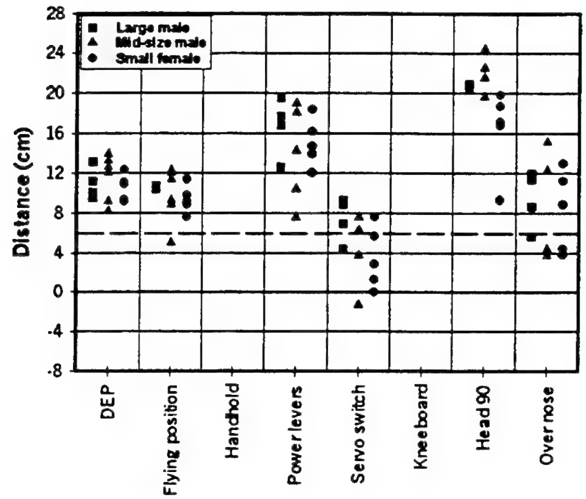
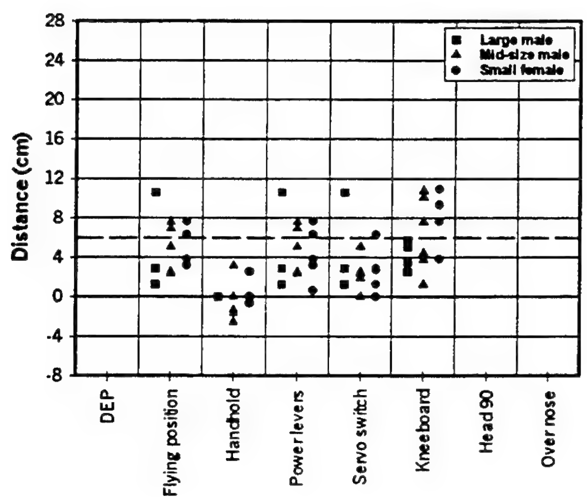
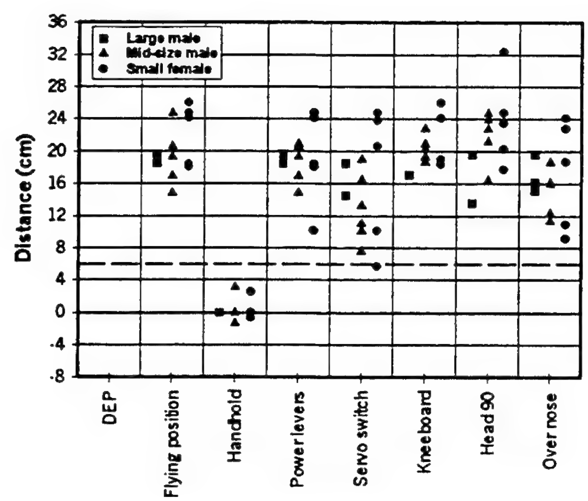


Figure B-3. Clearance between right-side forward airbag and subjects' NVGs. Positive distances characterize clearance. Distances less than or equal to 0 cm represent contact. A distance of 0 cm corresponds to brushing contact, while larger negative numbers indicate increasing contact severity. The dashed horizontal line represents the 6 cm distance from the forward airbag taken to represent probable contact due to dynamic overshoot.

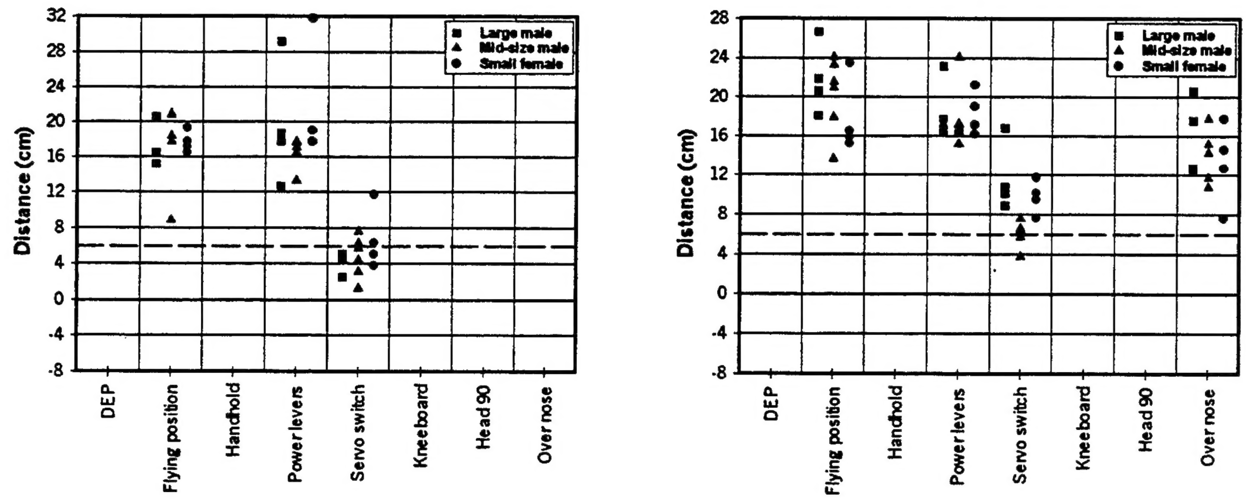


(a) Lower outboard arm



(b) Upper outboard arm

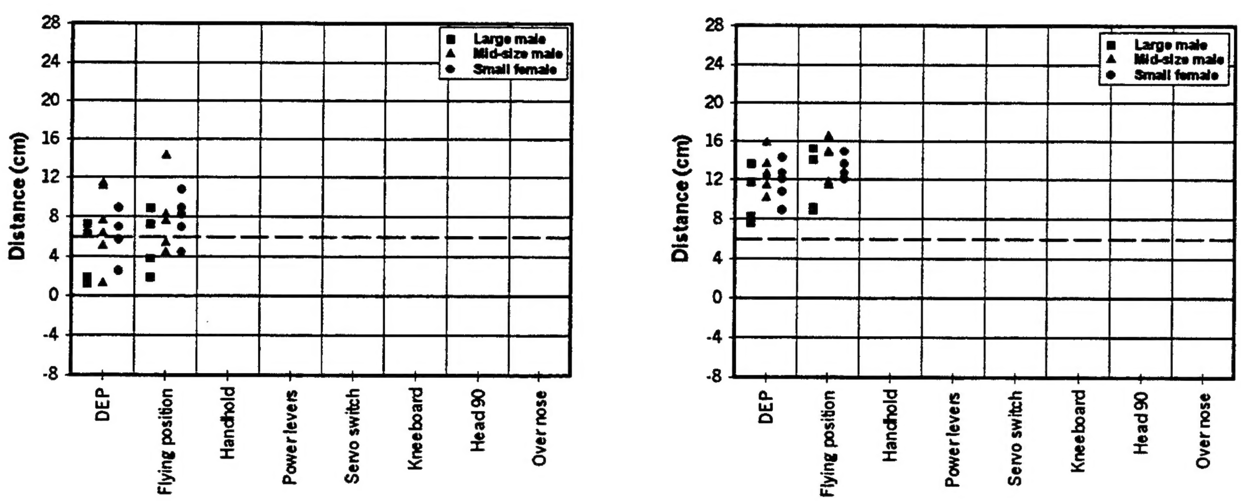
Figure B-4. Clearance between right-side forward airbag and subjects' outboard arms. Positive distances characterize clearance. Distances less than or equal to 0 cm represent contact. A distance of 0 cm corresponds to brushing contact, while larger negative numbers indicate increasing contact severity. The dashed horizontal line represents the 6 cm distance from the forward airbag taken to represent probable contact due to dynamic overshoot.



(a) Lower inboard arm

(b) Upper inboard arm

Figure B-5. Clearance between right-side forward airbag and subjects' inboard arms. Positive distances characterize clearance. Distances less than or equal to 0 cm represent contact. A distance of 0 cm corresponds to brushing contact, while larger negative numbers indicate increasing contact severity. The dashed horizontal line represents the 6 cm distance from the forward airbag taken to represent probable contact due to dynamic overshoot.



(a) Left leg

(b) Right leg

Figure B-6. Clearance between right-side forward airbag and subjects' legs. Positive distances characterize clearance. Distances less than or equal to 0 cm represent contact. A distance of 0 cm corresponds to brushing contact, while larger negative numbers indicate increasing contact severity. The dashed horizontal line represents the 6 cm distance from the forward airbag taken to represent probable contact due to dynamic overshoot.

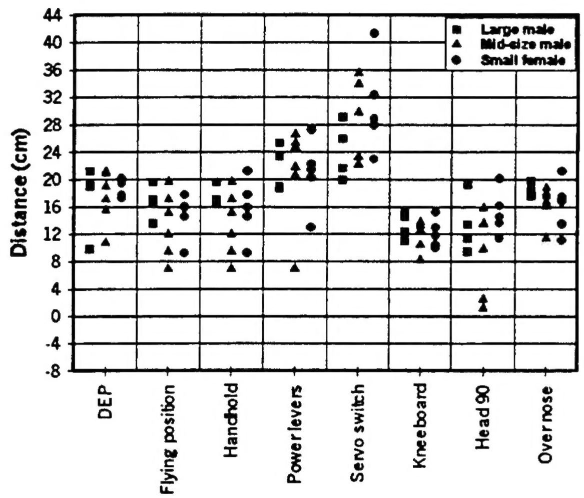


Figure B-7. Clearance between right-side lateral airbag and subjects' faces. Positive distances characterize clearance. Distances less than or equal to 0 cm represent contact. A distance of 0 cm corresponds to brushing contact, while larger negative numbers indicate increasing contact severity.

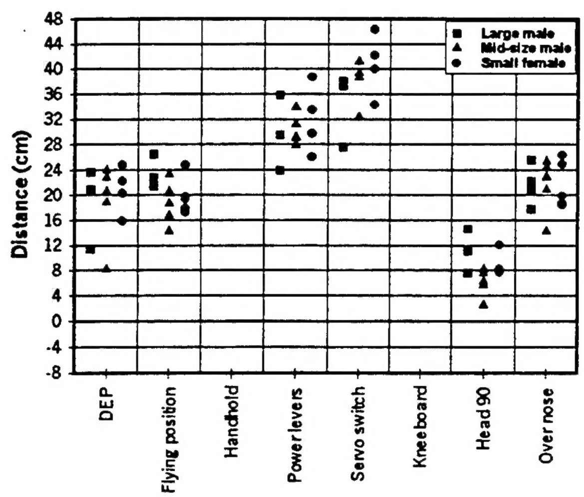


Figure B-8. Clearance between right-side lateral airbag and subjects' NVGs. Positive distances characterize clearance. Distances less than or equal to 0 cm represent contact. A distance of 0 cm corresponds to brushing contact, while larger negative numbers indicate increasing contact severity.

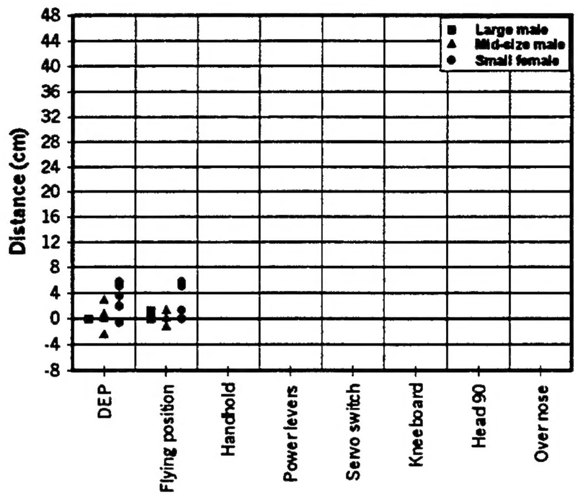
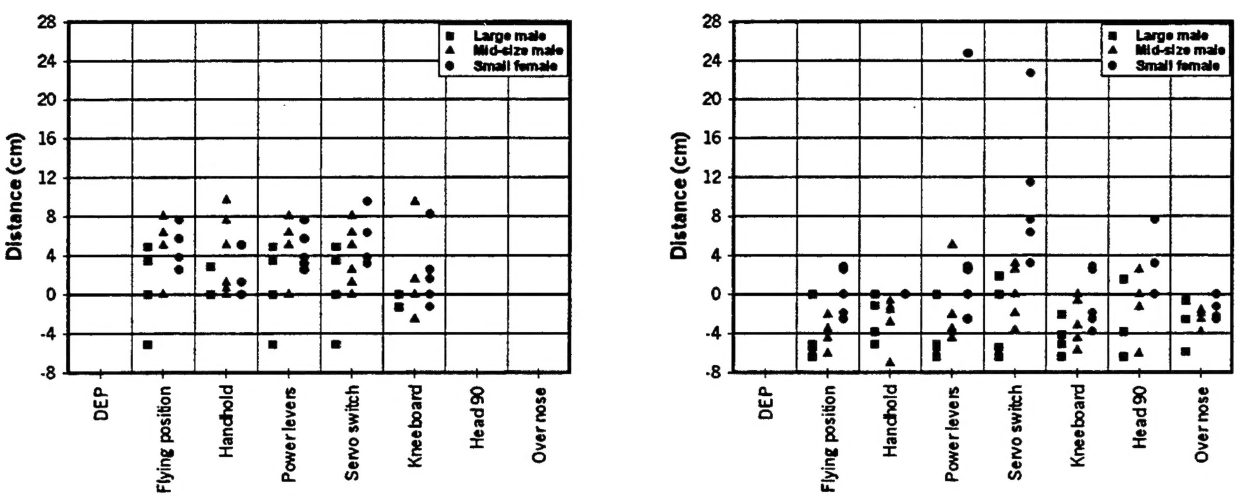


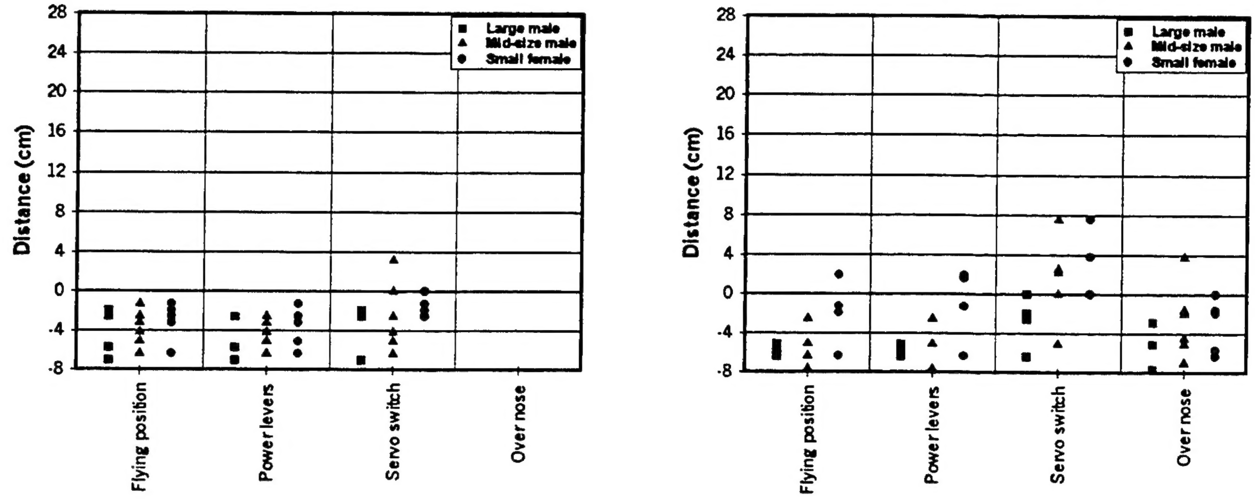
Figure B-9. Clearance between right-side lateral airbag and subjects' right legs. Positive distances characterize clearance. Distances less than or equal to 0 cm represent contact. A distance of 0 cm corresponds to brushing contact, while larger negative numbers indicate increasing contact severity.



(a) Lower outboard arm

(b) Upper outboard arm

Figure B-10. Clearance between right-side lateral airbag and subjects' outboard arms. Positive distances characterize clearance. Distances less than or equal to 0 cm represent contact. A distance of 0 cm corresponds to brushing contact, while larger negative numbers indicate increasing contact severity.



(a) Lower outboard arm

(b) Upper outboard arm

Figure B-11. Clearance between left-side lateral airbag and subjects' outboard arms. Positive distances characterize clearance. Distances less than or equal to 0 cm represent contact. A distance of 0 cm corresponds to brushing contact, while larger negative numbers indicate increasing contact severity.